SNOQUALMIE RIVER HYDROLOGIC STUDY

EVALUATION OF FLOODING TRENDS AND CURRENT CONDITIONS

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HERRERA

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Some Key Findings

- Trends towards increasing flows in the fall and spring, and decreasing flows in the summer
- Increasing frequency of high flow events (approximately Phase 2)
- Increasing peak flows (trend is not statistically significant)
- Trends hard to determine due to variability and limited data

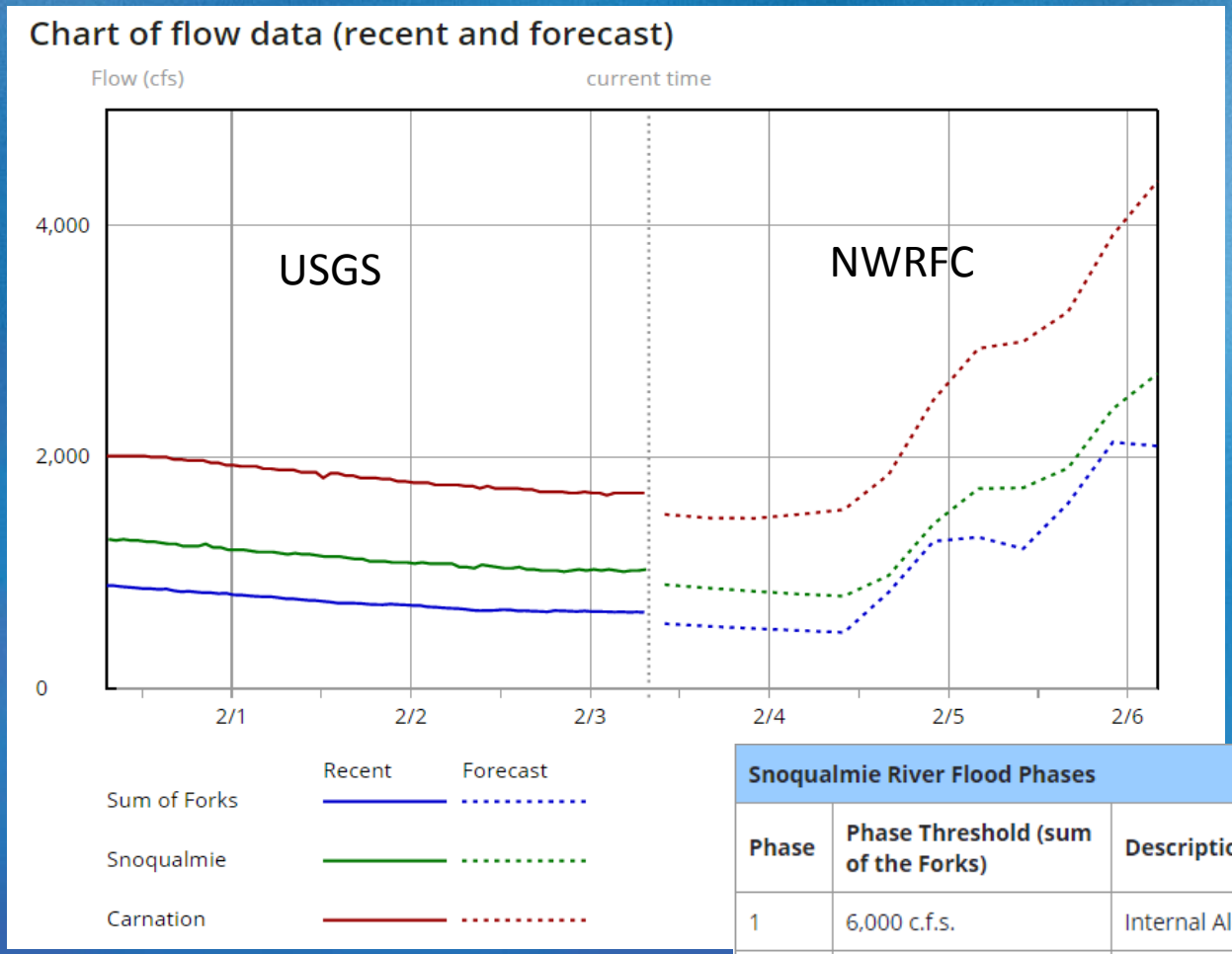
Study Objectives

- Review USGS gaging program
- Evaluate Changes to Snoqualmie River Flow
  - Examine potential drivers of change

USGS Gages and Early Flood Warning

"Sum of Forks"

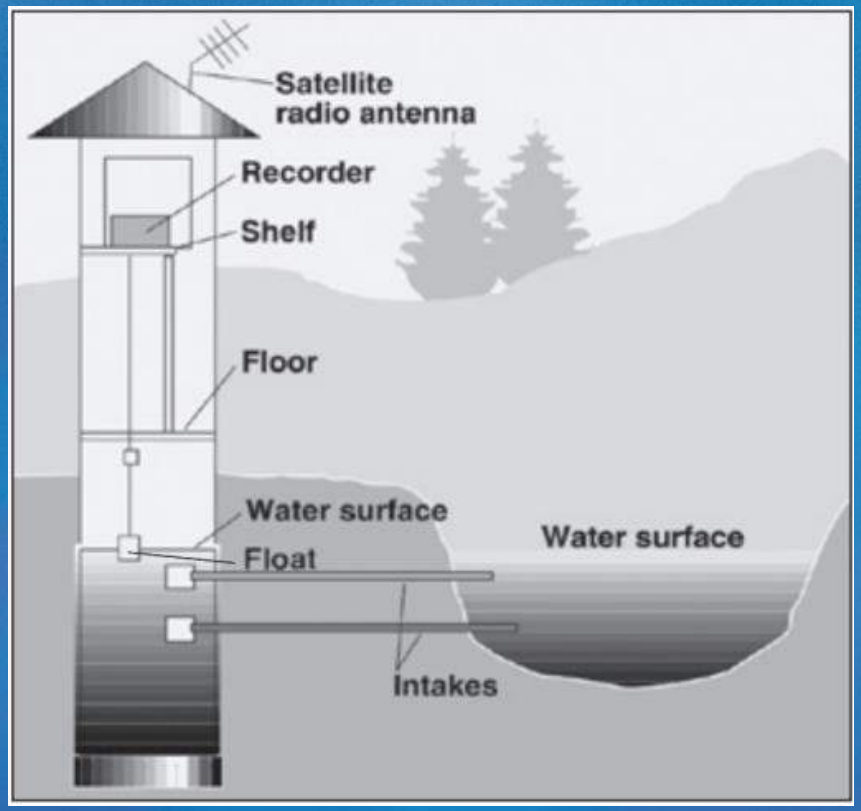
King County Flood Warning uses USGS Gages



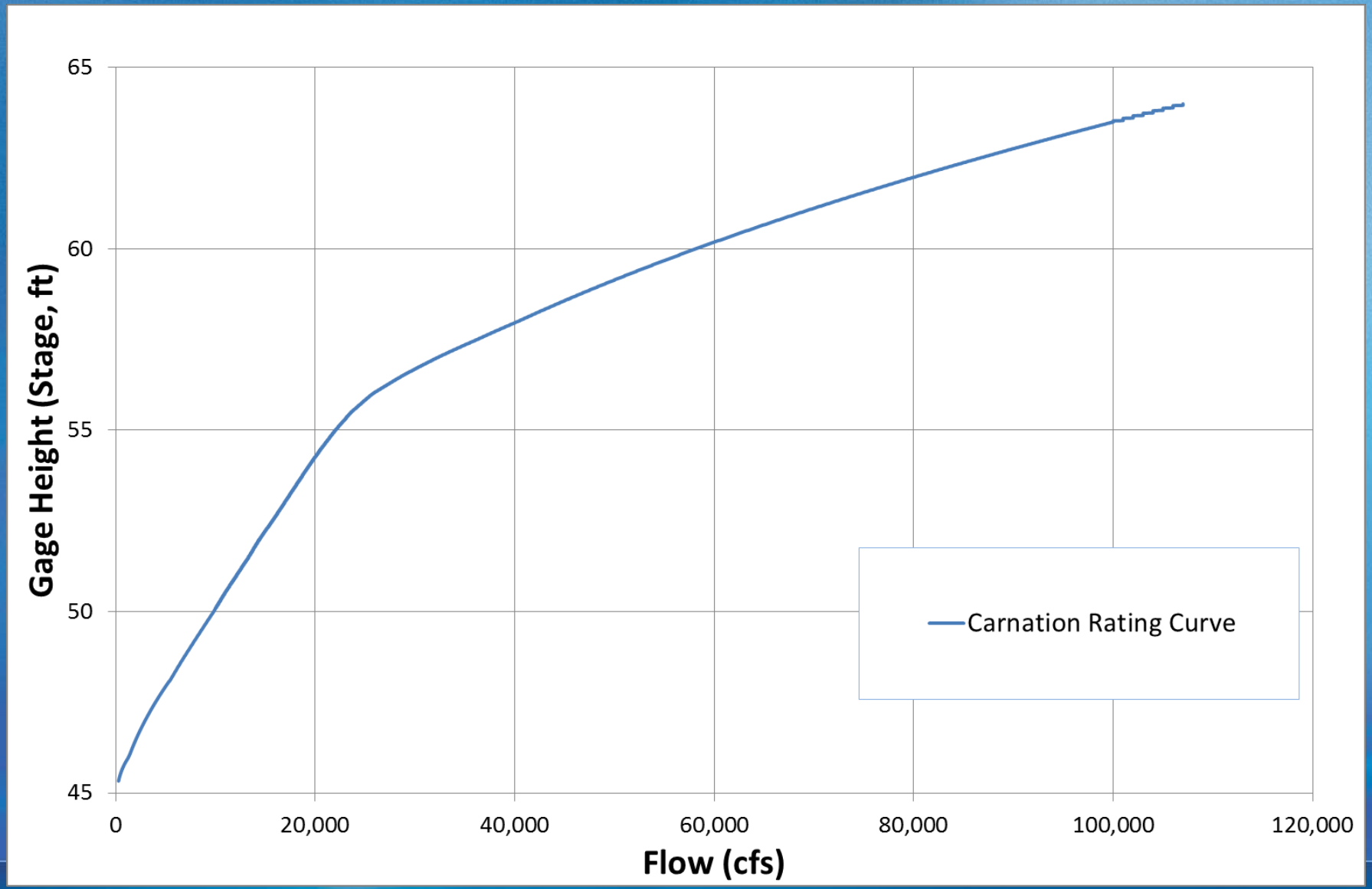
Snoqualmie River Flood Phases

Phase	Phase Threshold (sum of the Forks)	Description
1	6,000 c.f.s.	Internal Alert
2	12,000 c.f.s.	Lowland flooding
3	20,000 c.f.s.	Flooding of varied depths occurs in the entire Snoqualmie Valley
4	38,000 c.f.s.	Some residential areas may experience dangerous high velocities and flooding of homes.

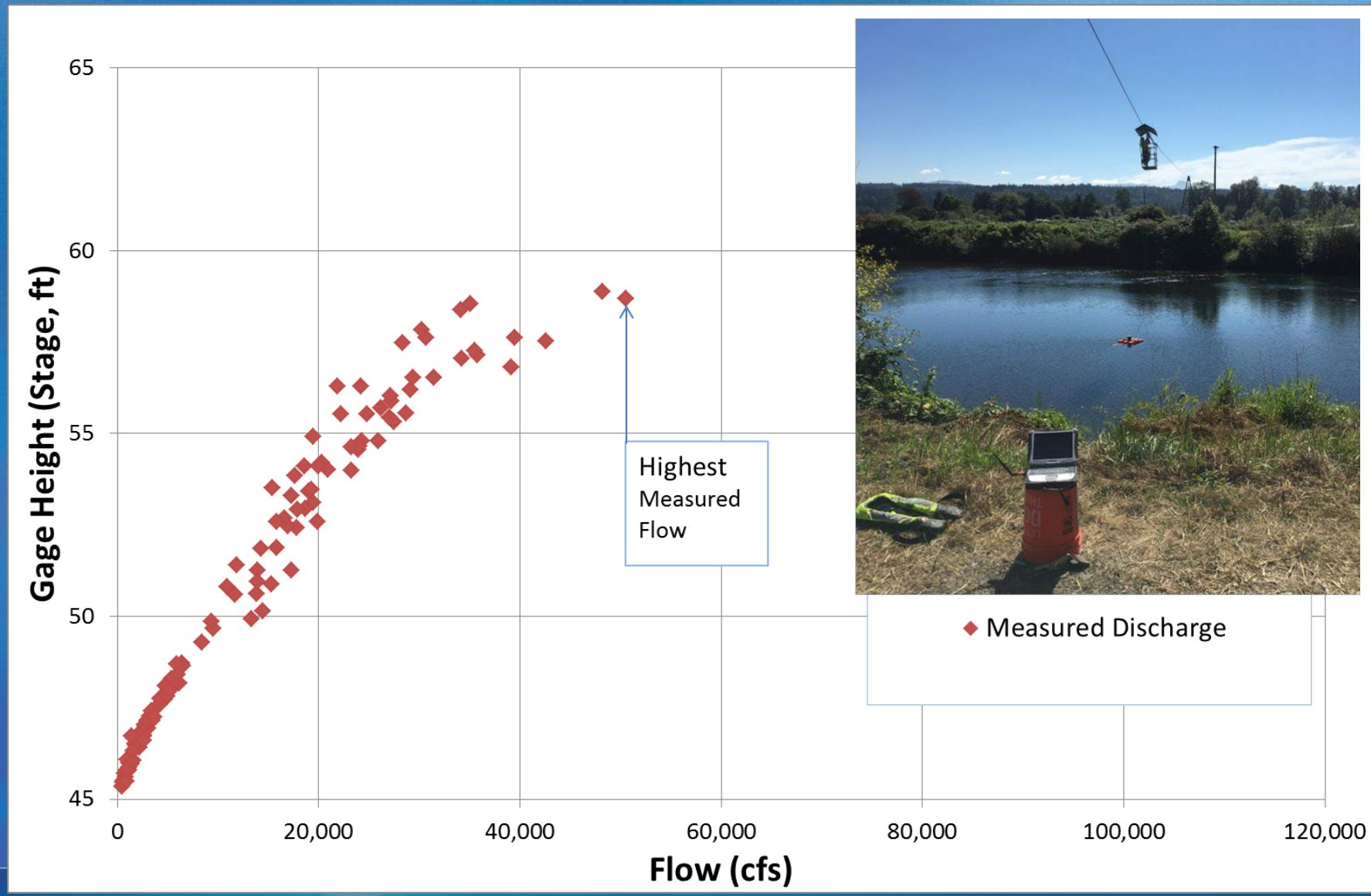
USGS Gaging Measures Stage



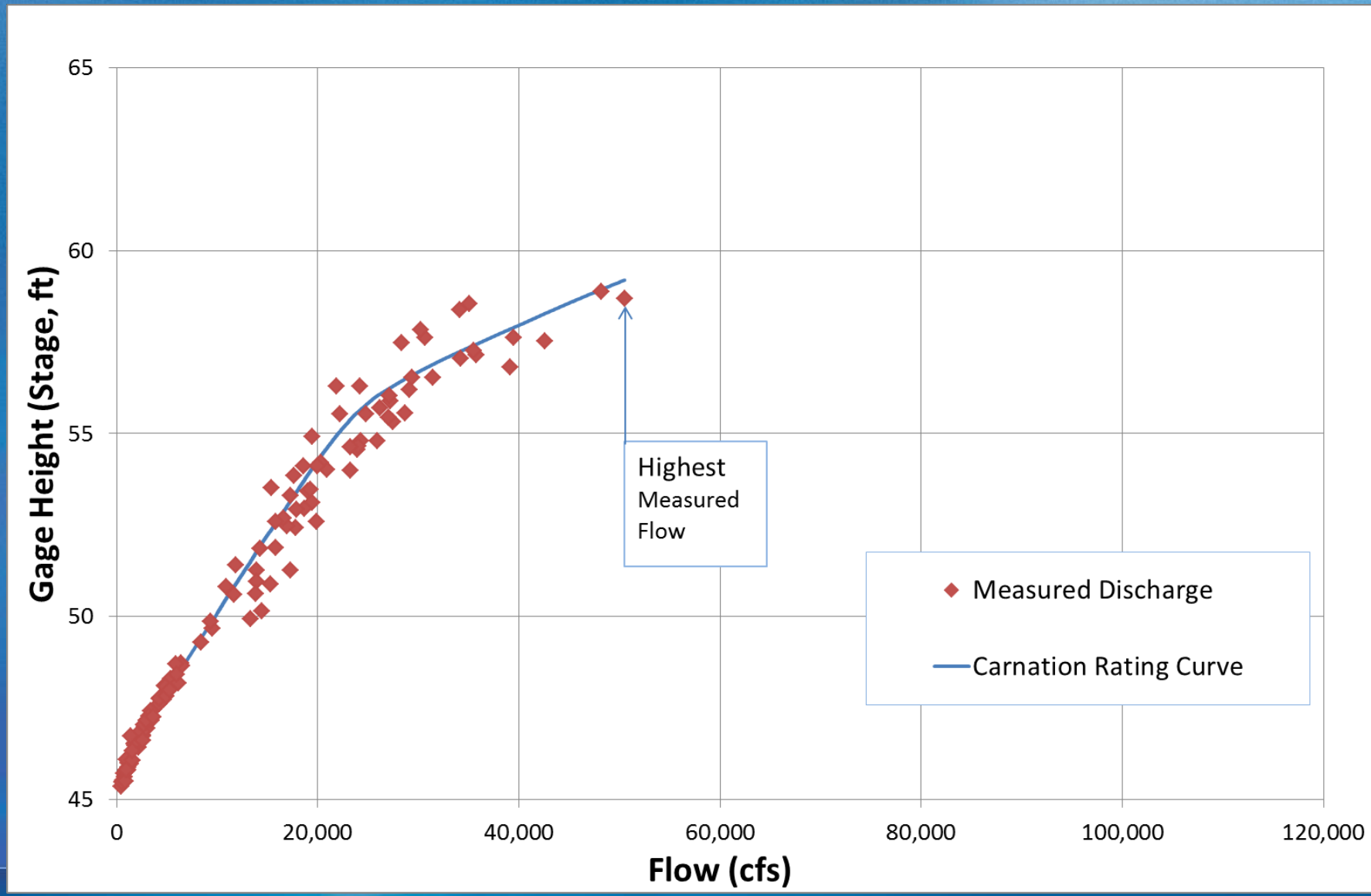
Rating Curve Converts Stage to Flow



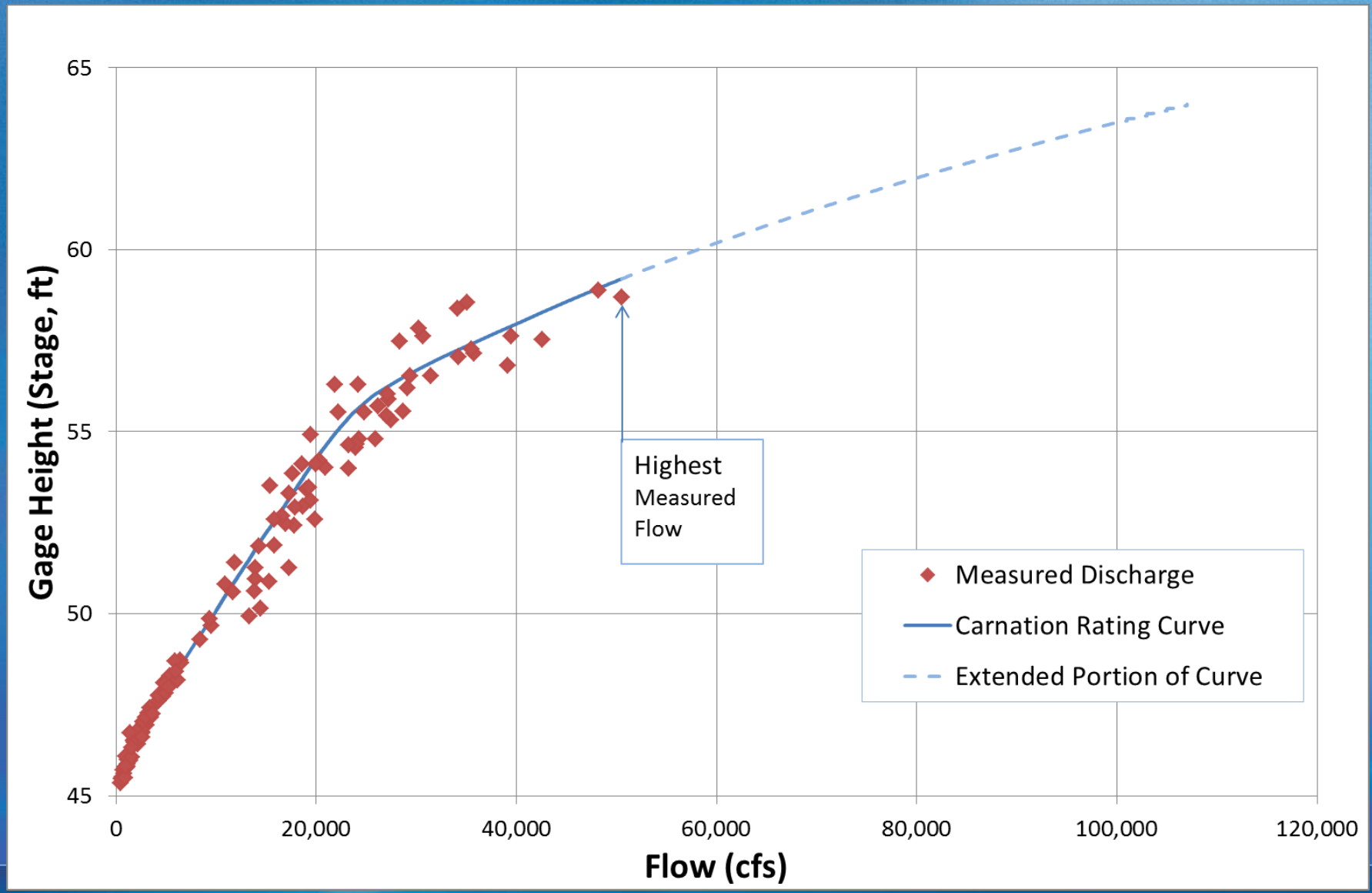
Physical Flow Measurement



Measurements Define Curve



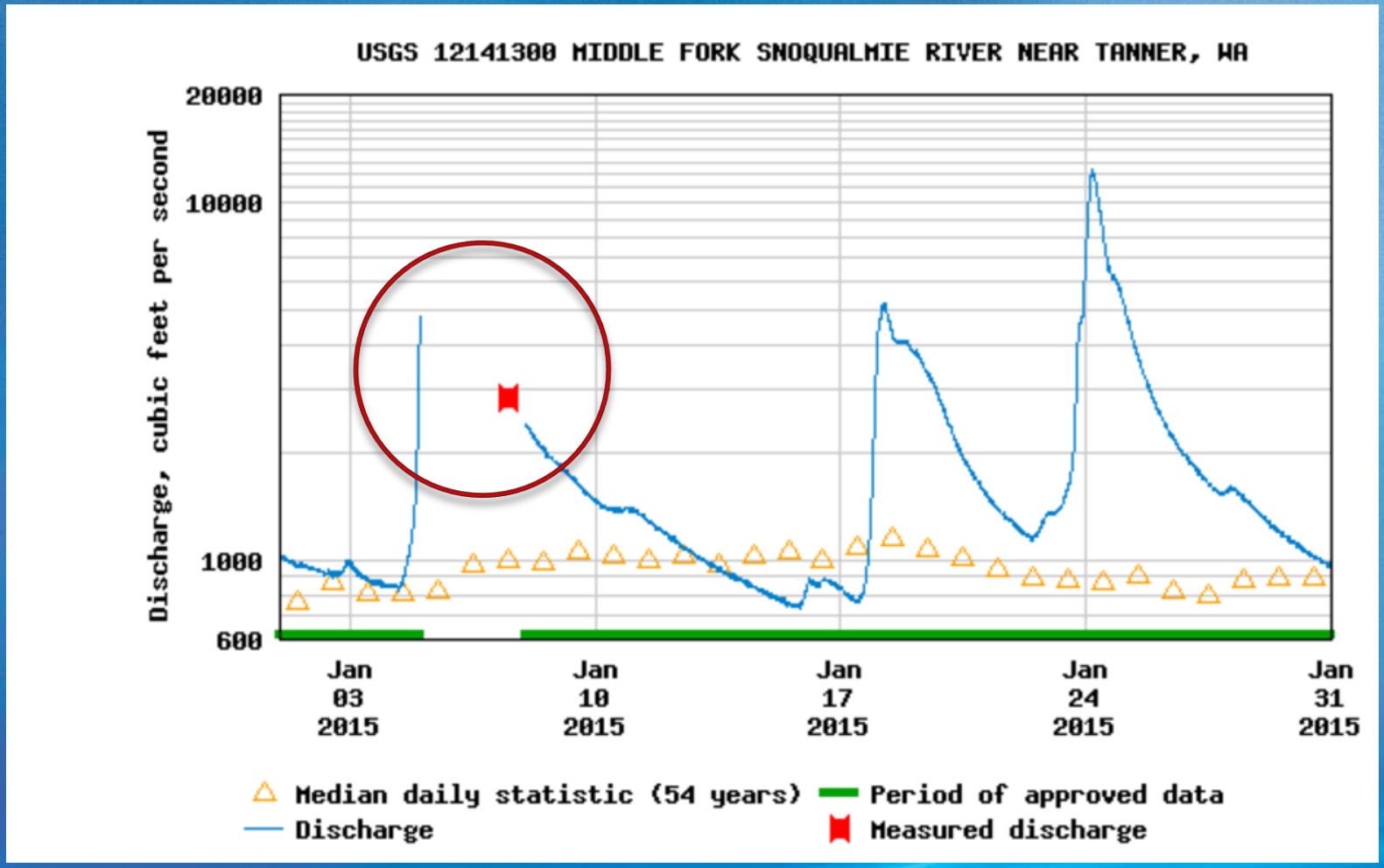
Curve is Extended for High Flow Estimation



Carnation Gage Complicated at High Flows

Flood: November 1995

Other Gaging Issues – Sometimes Gages Fail

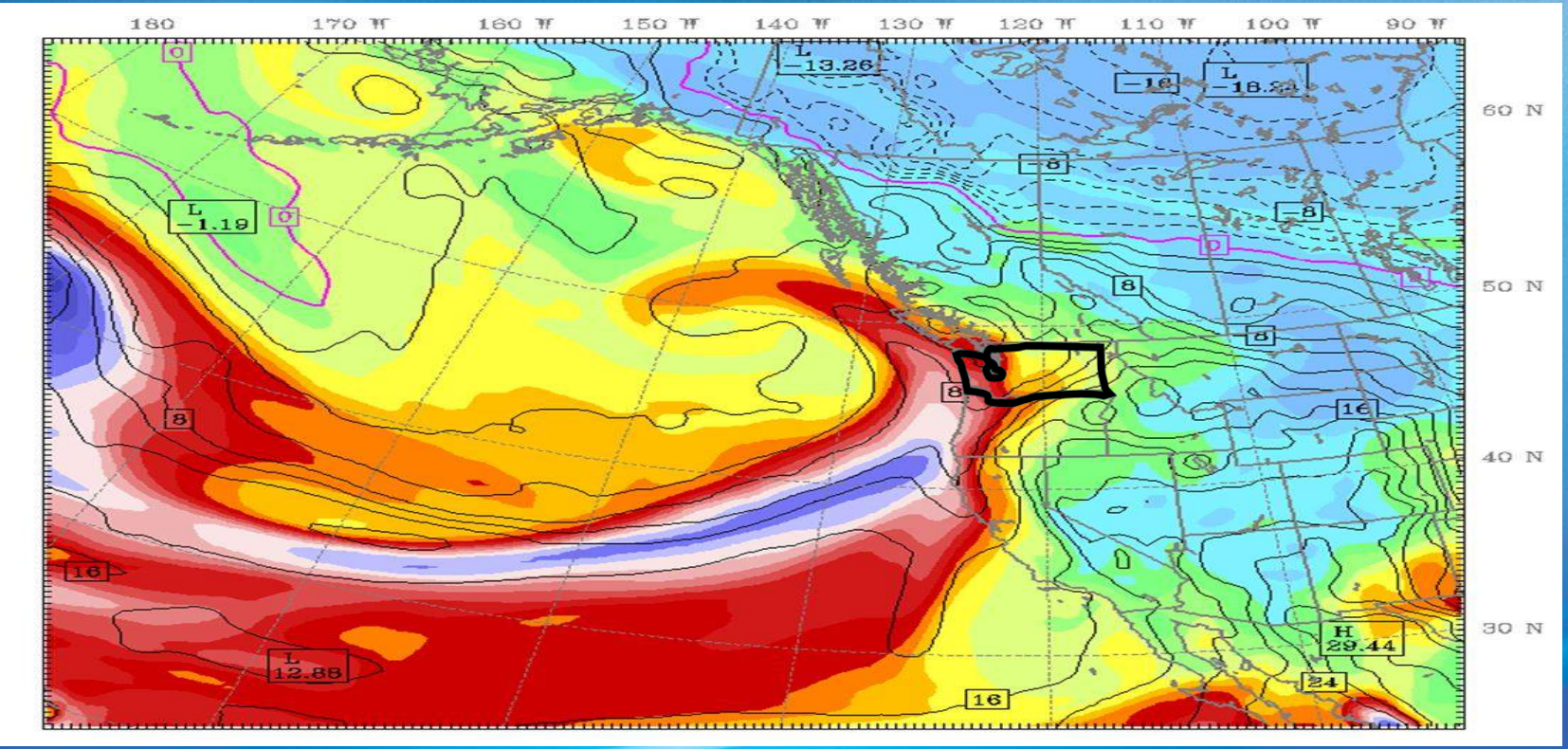


Key Findings Review of USGS Gaging Program

- Best source of current and historical flow information
- Increased uncertainty with high flow estimates
- Carnation gage is less accurate in real time
- USGS is addressing inaccuracies

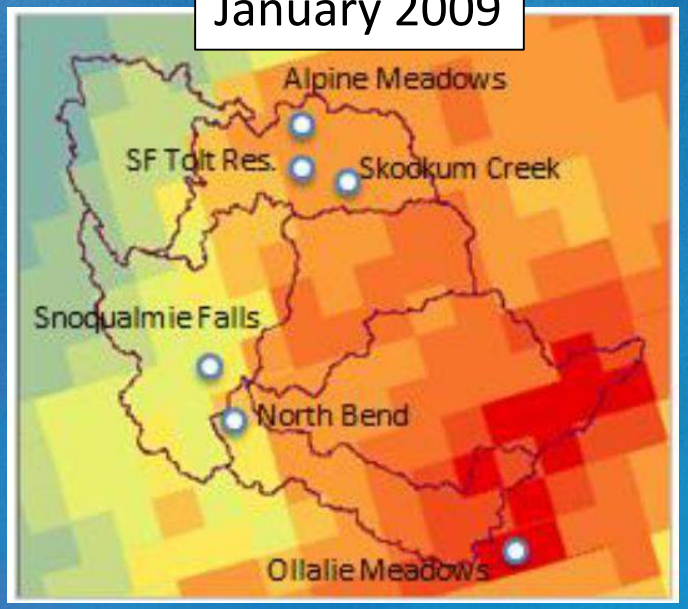
Anatomy of A Flood Discussion

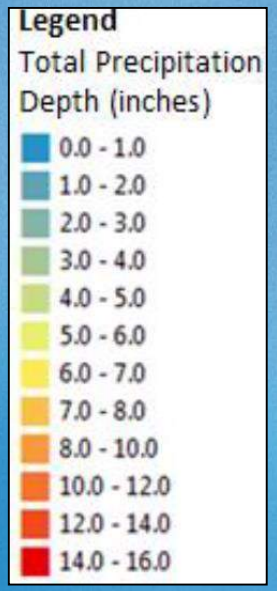
- January 2009, January 2015, December 2015
- “Atmospheric River” storms



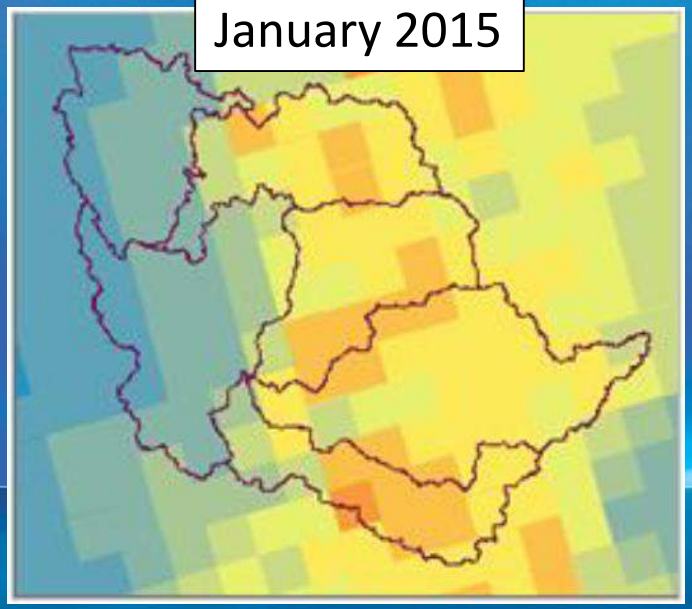
Storm Comparison – 48 Hour Precipitation

January 2009

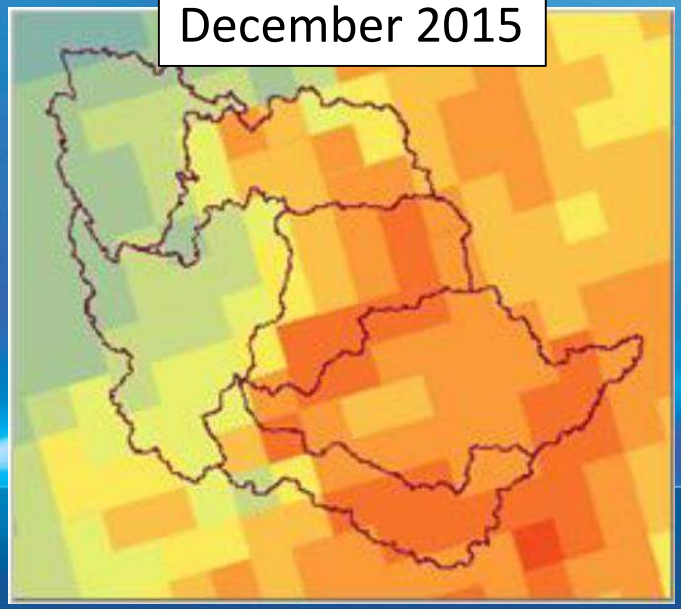




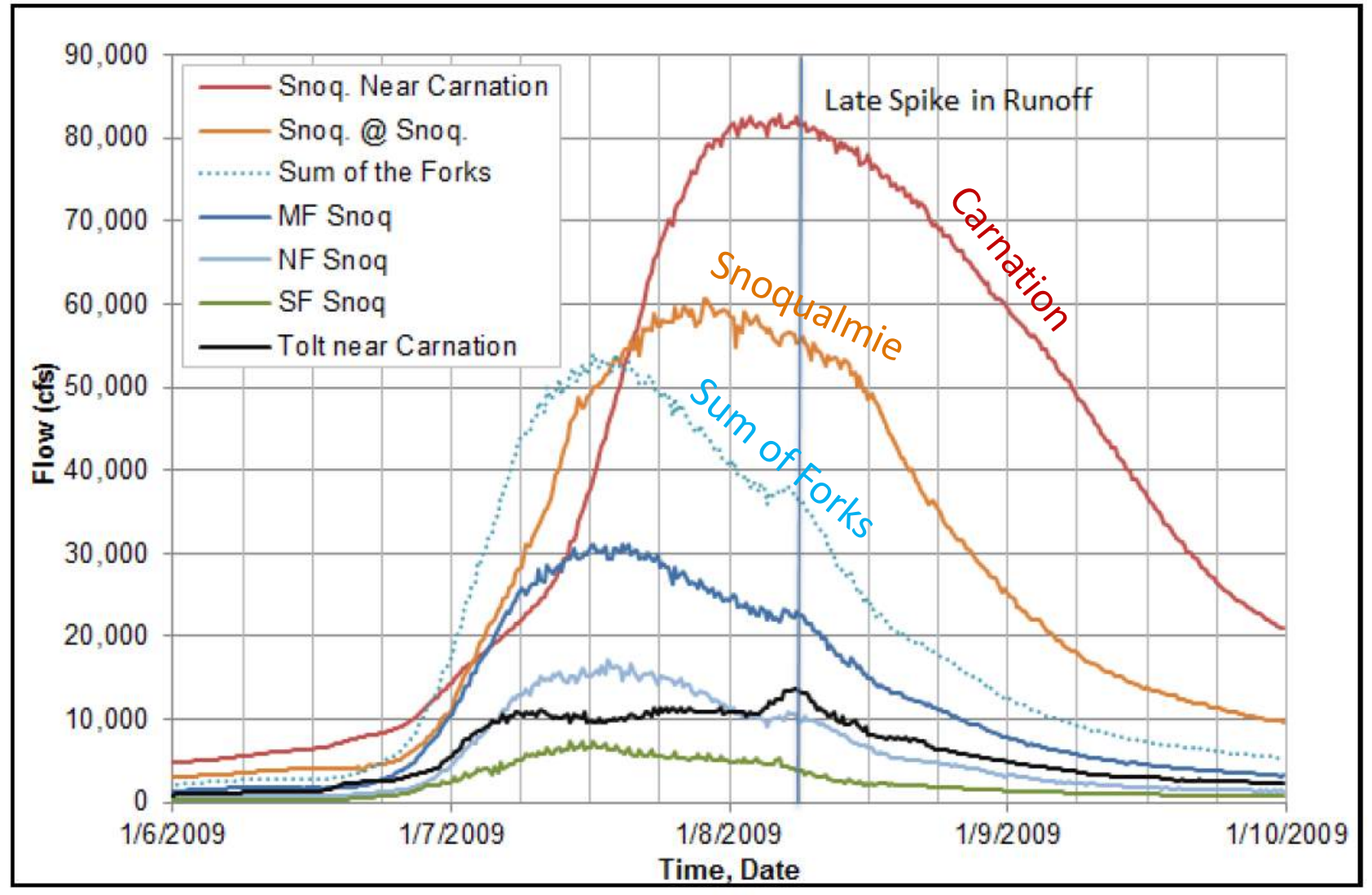
January 2015



December 2015

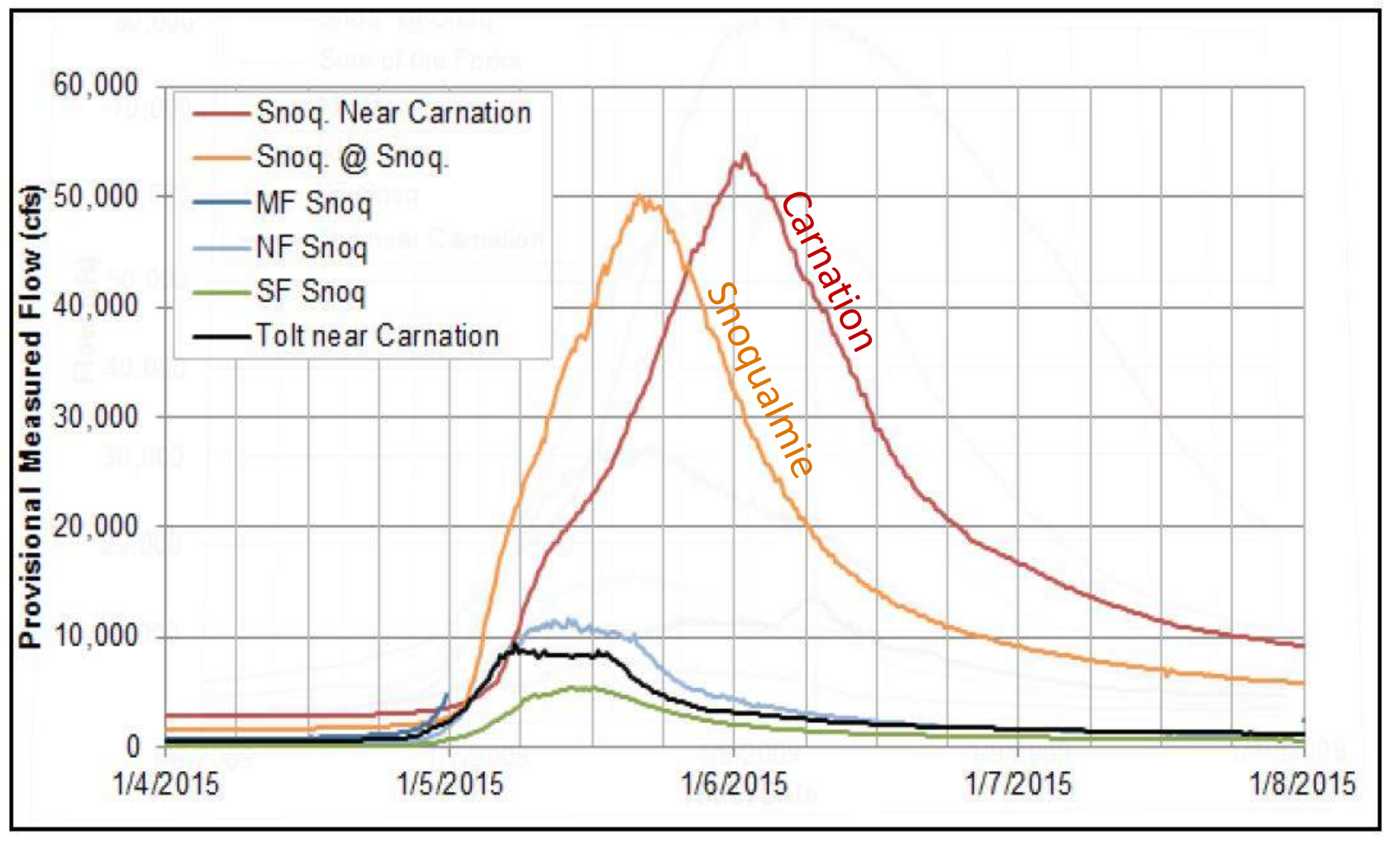


January 2009 Flood Hydrographs

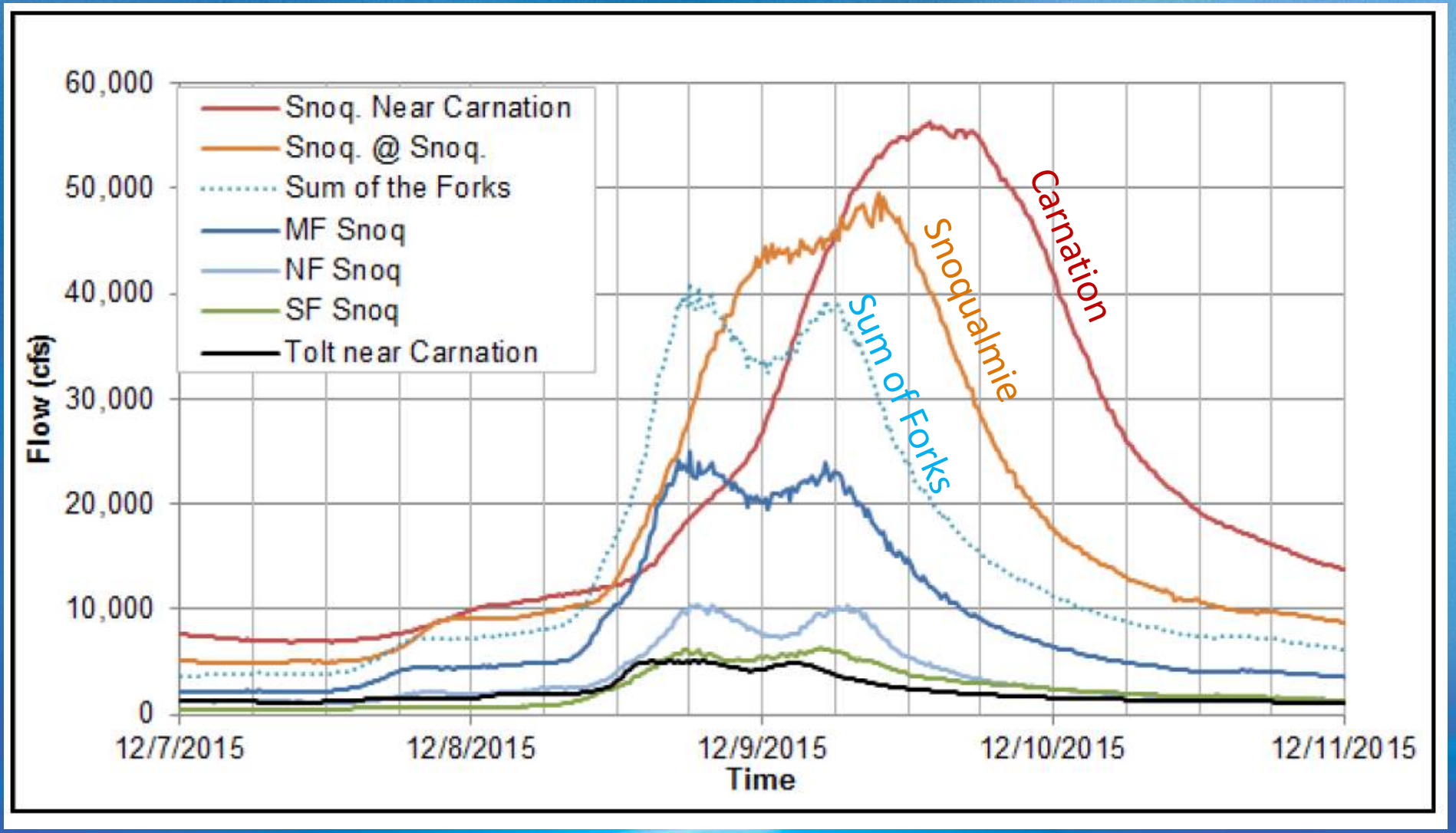


Late Spike in Runoff on Tolt

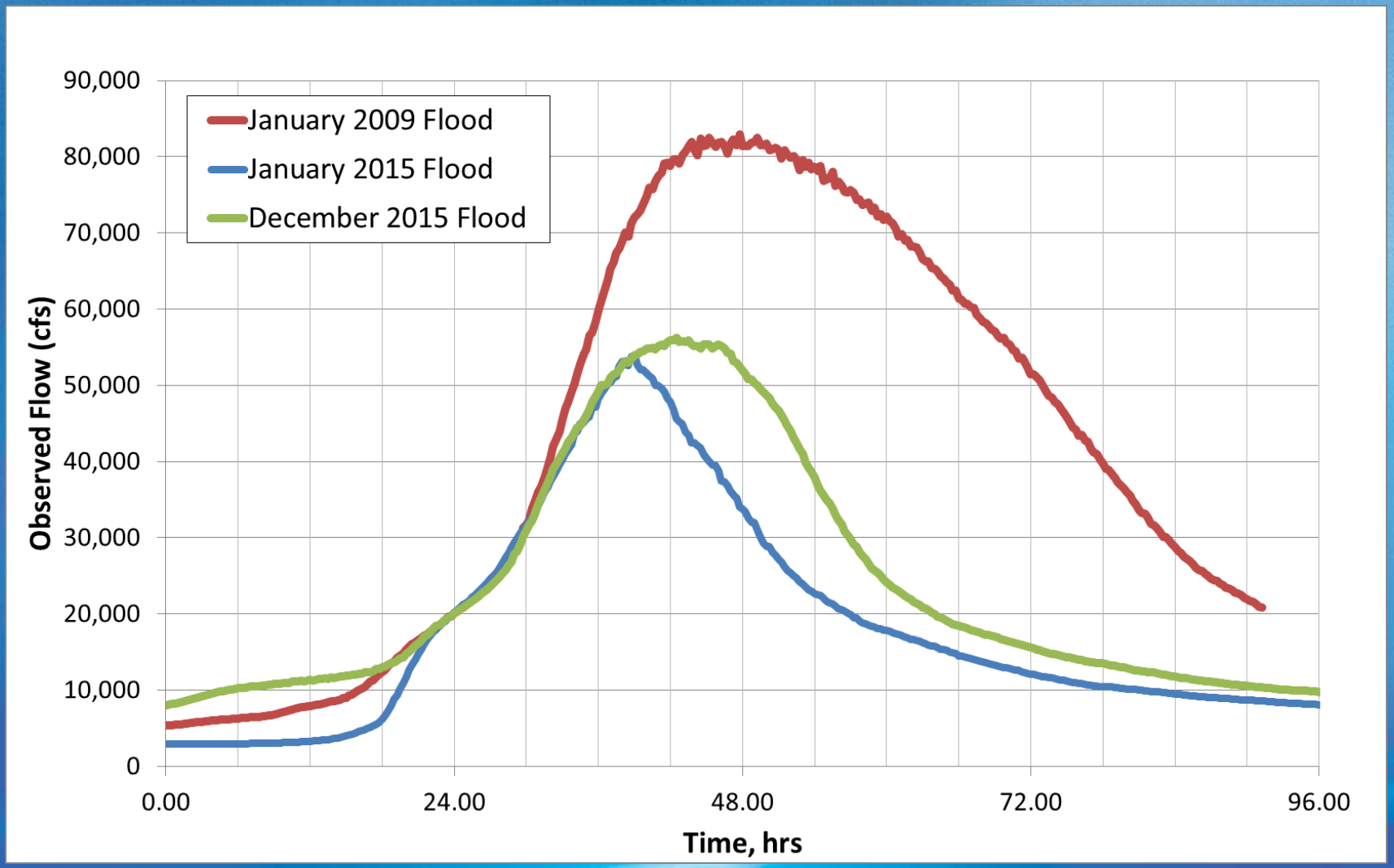
January 2015 Flood Hydrographs



December 2015 Flood Hydrographs



Hydrographs at Carnation Gage



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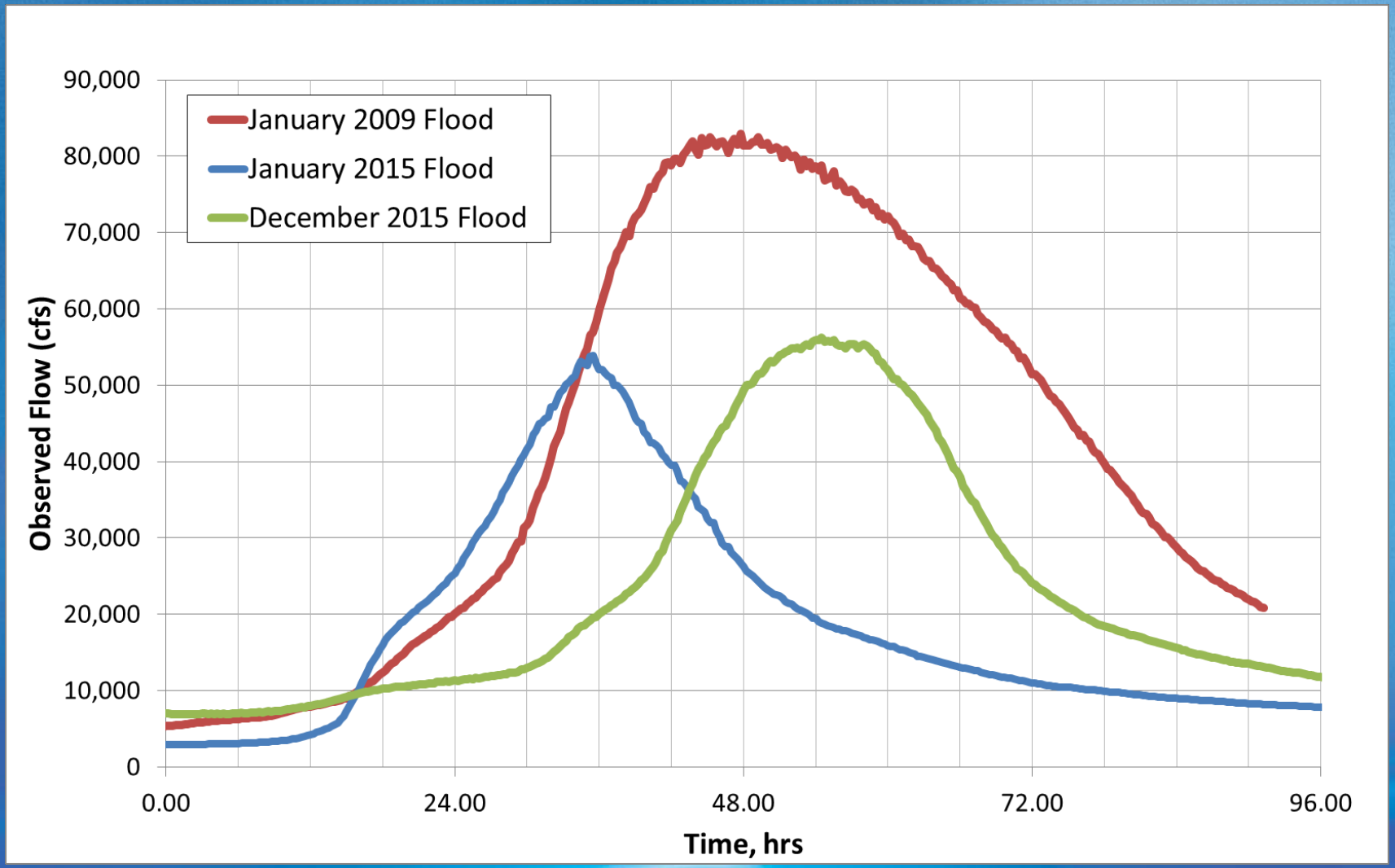


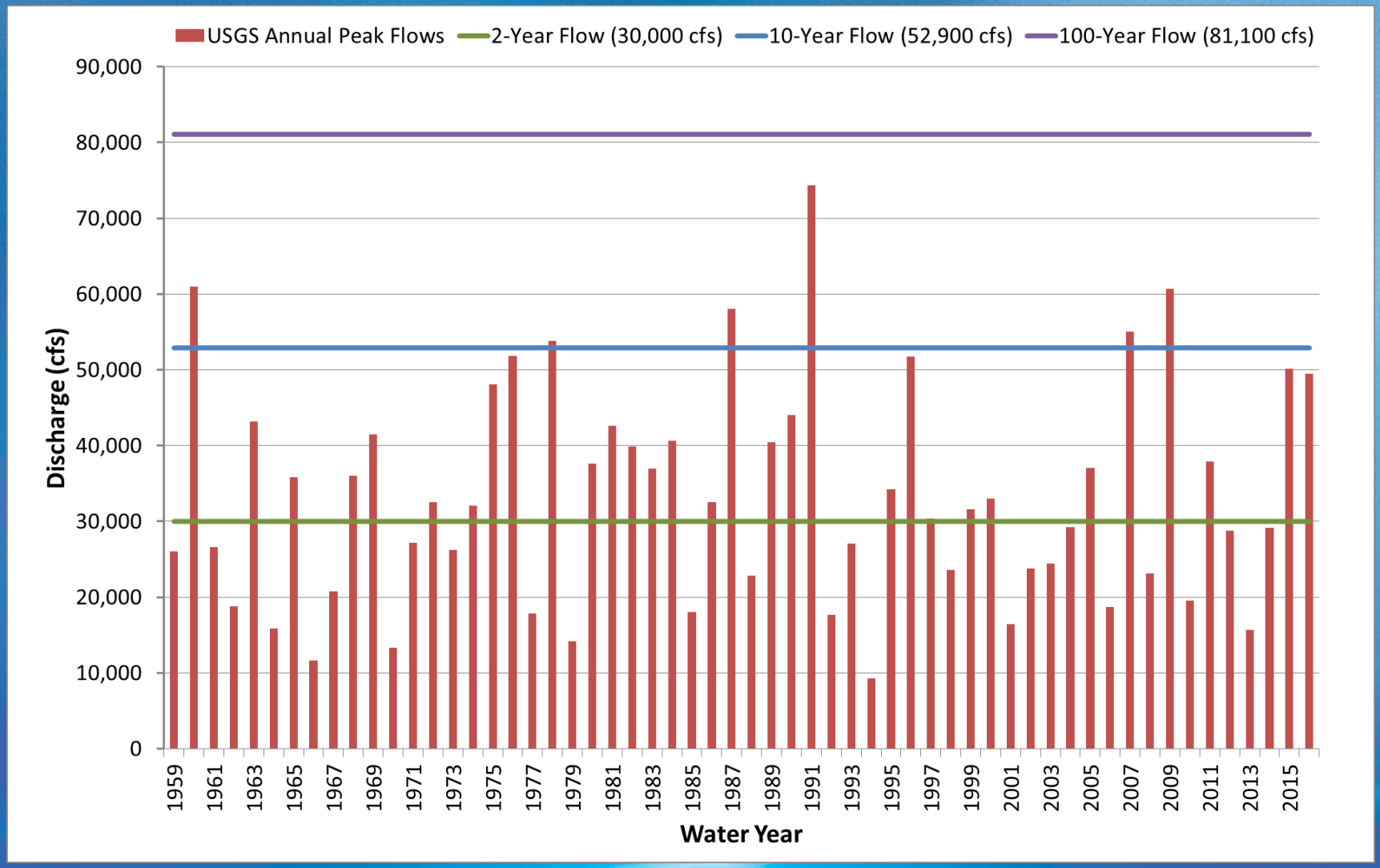
Key Findings Anatomy of a Flood

- Floods are Different
- Extent and duration of impacts correlate to peak flow, volume, and total flood duration.

Assessment of Hydrologic Trends

- Are Floods Getting Larger?
- Are Floods More Frequent?
- Are Floods Coming Faster?

Example of Peak Annual Flow Data (Snoqualmie Gage)



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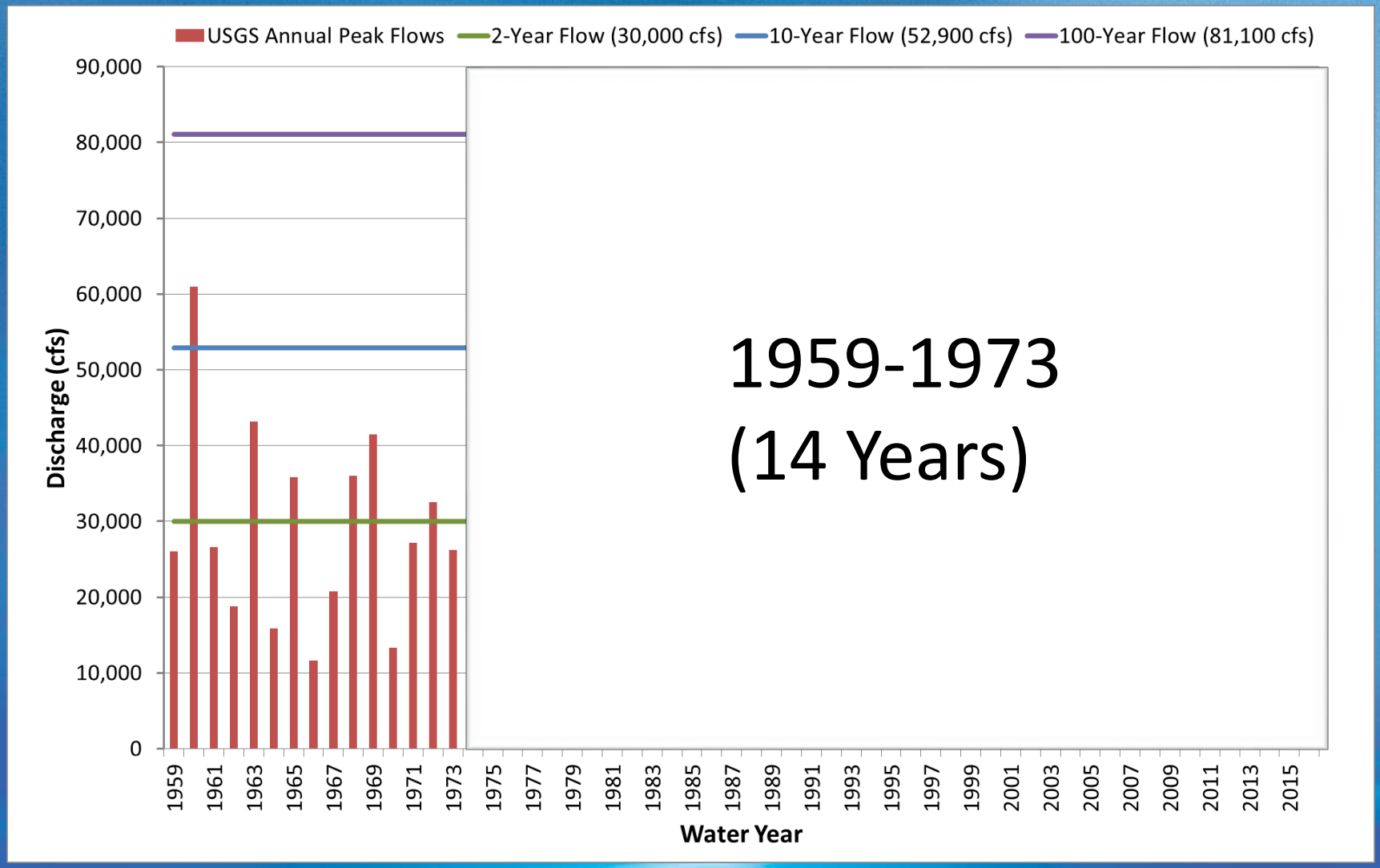

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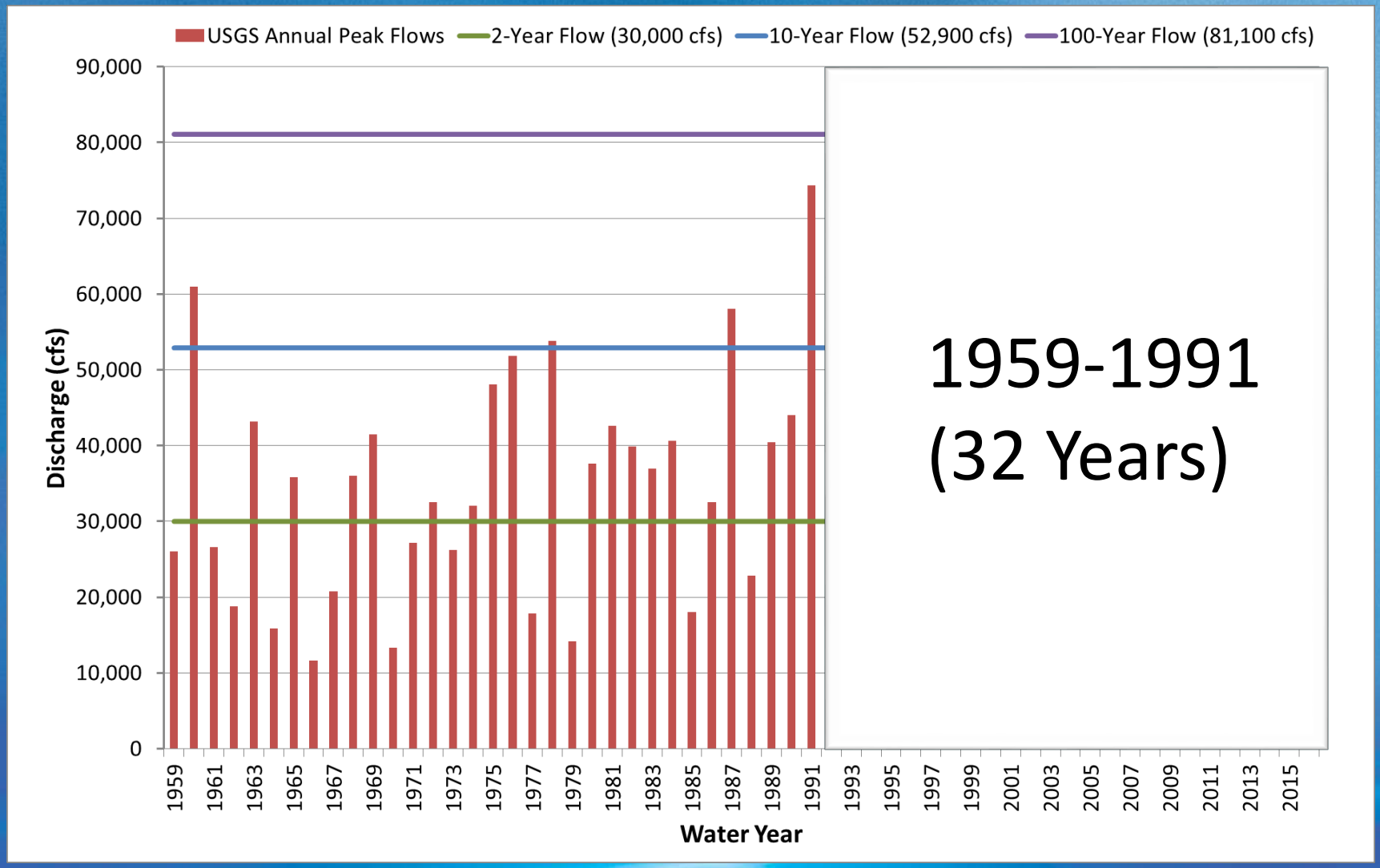

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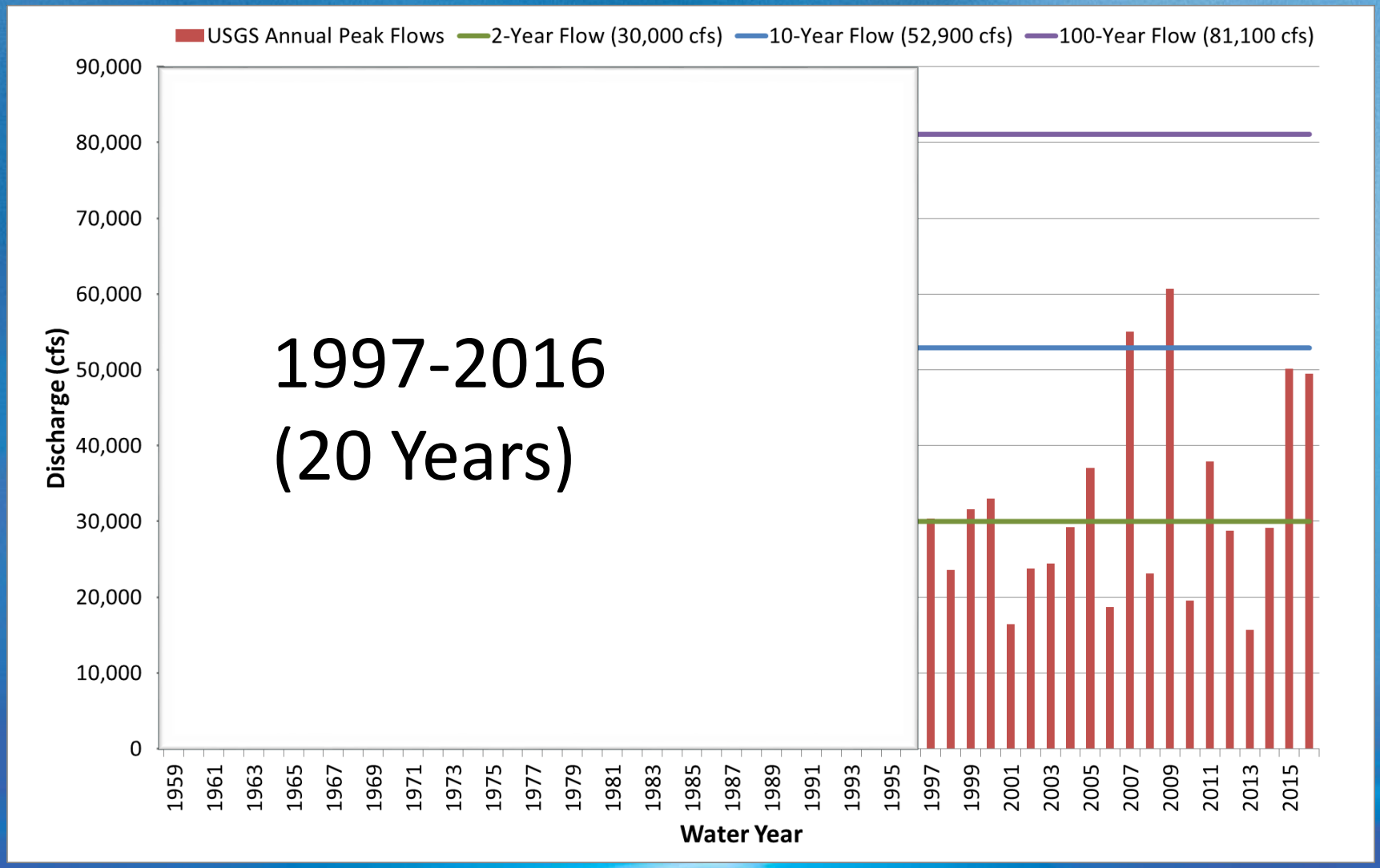

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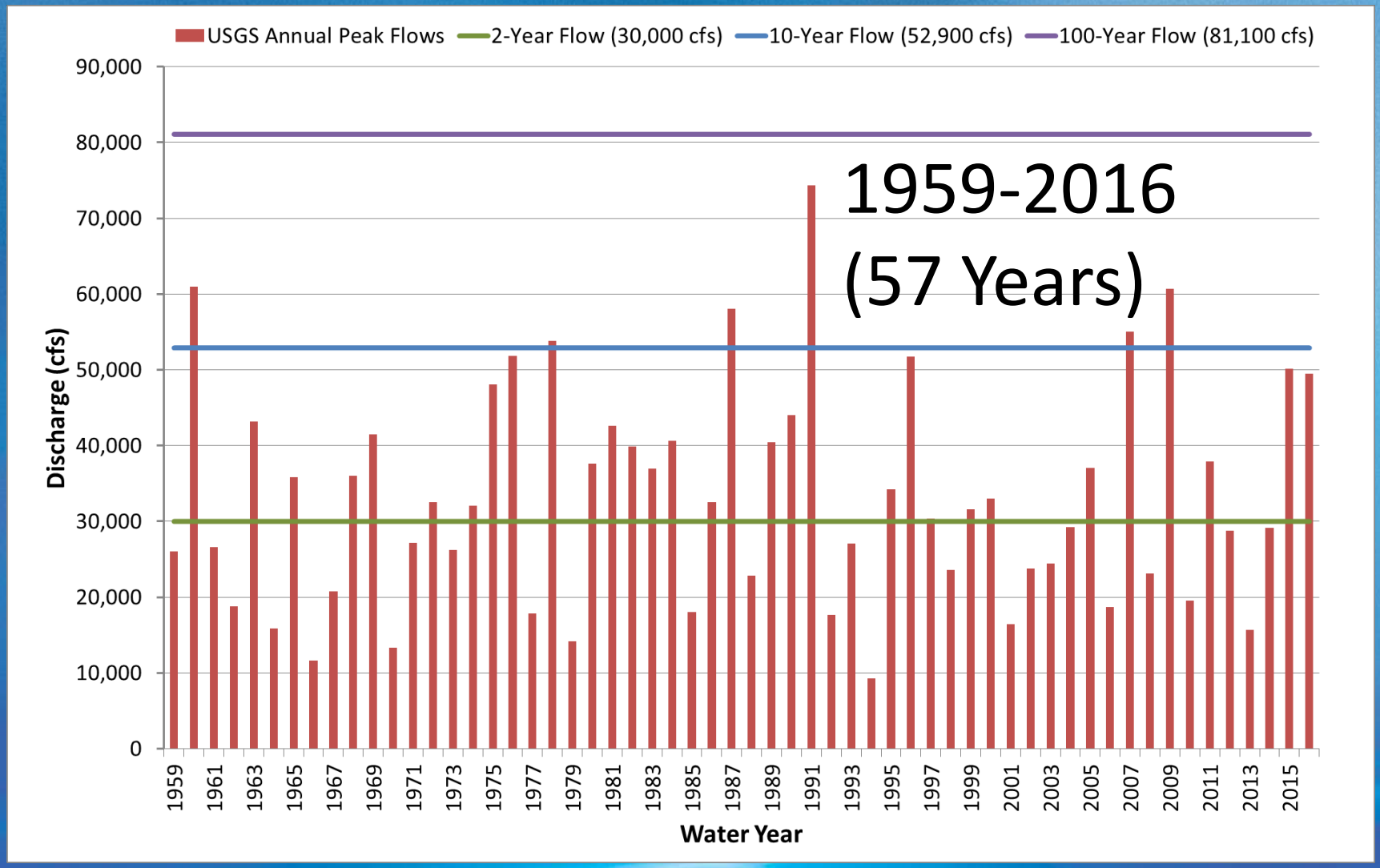
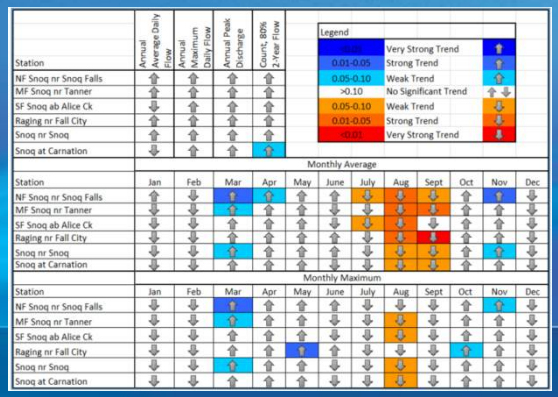


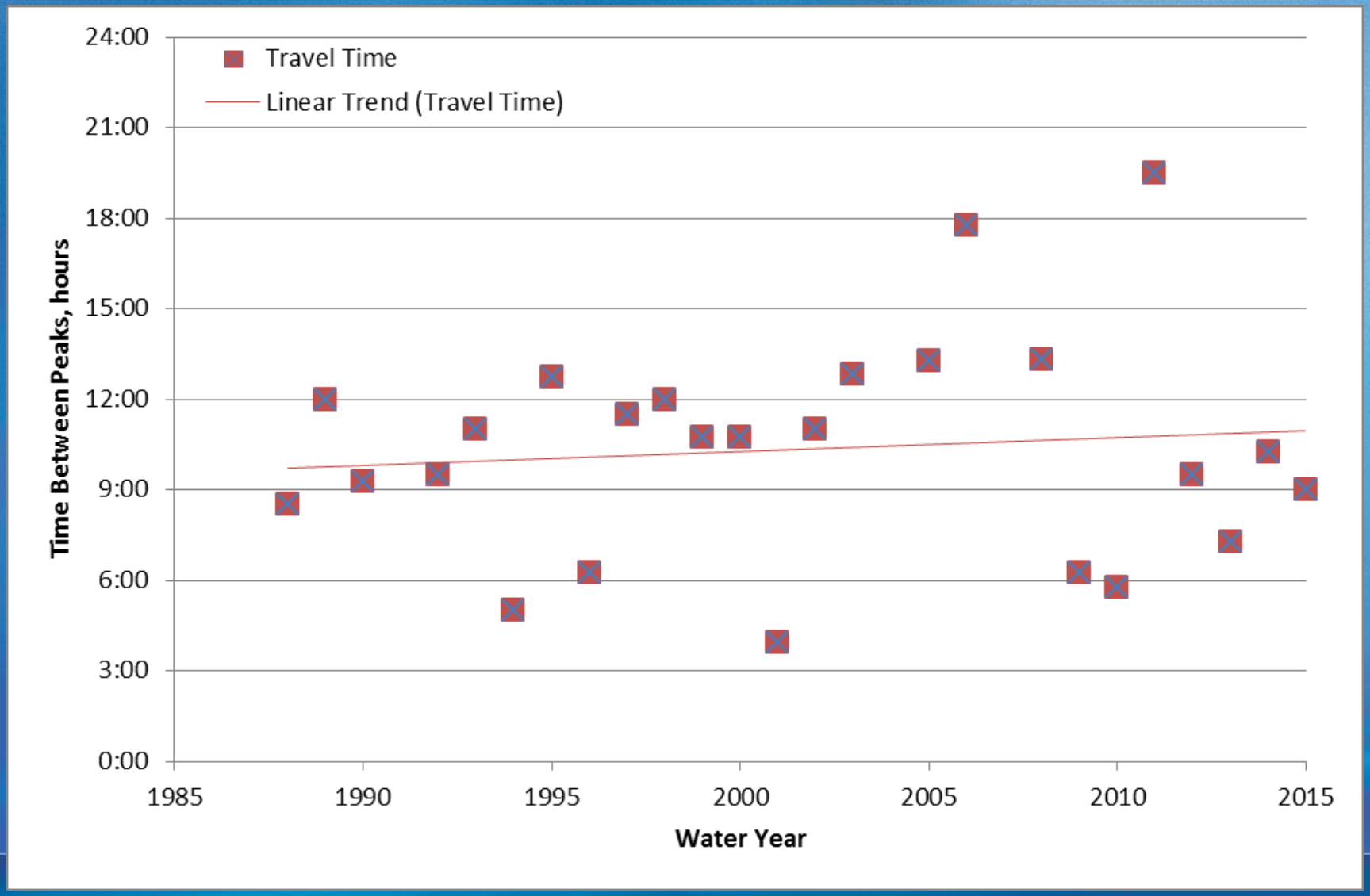
How are Flows Changing?

- Flow in summer
- Flow in spring
- Flow in the fall
- Frequency of high flow events
- Peak flow magnitude

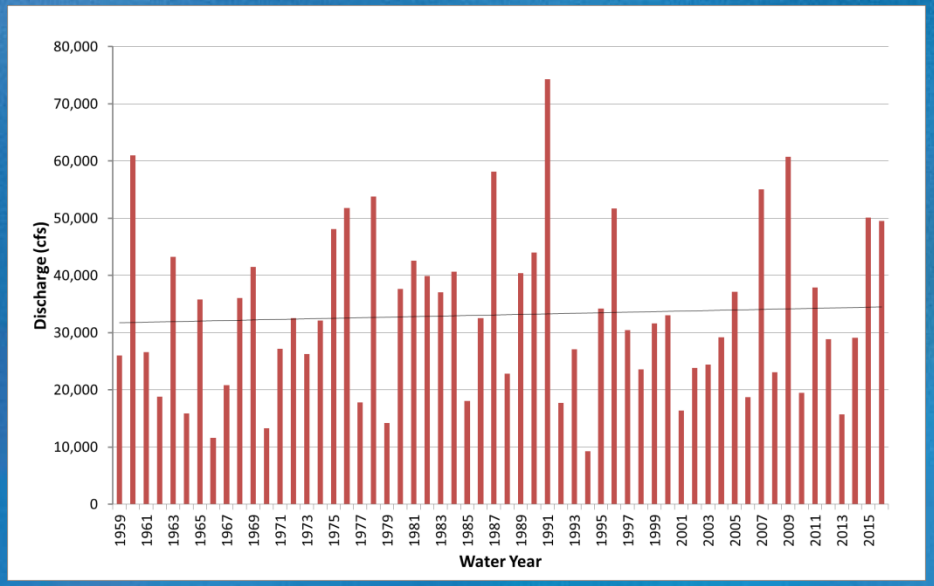
No statistically significant trend in peak flow magnitude

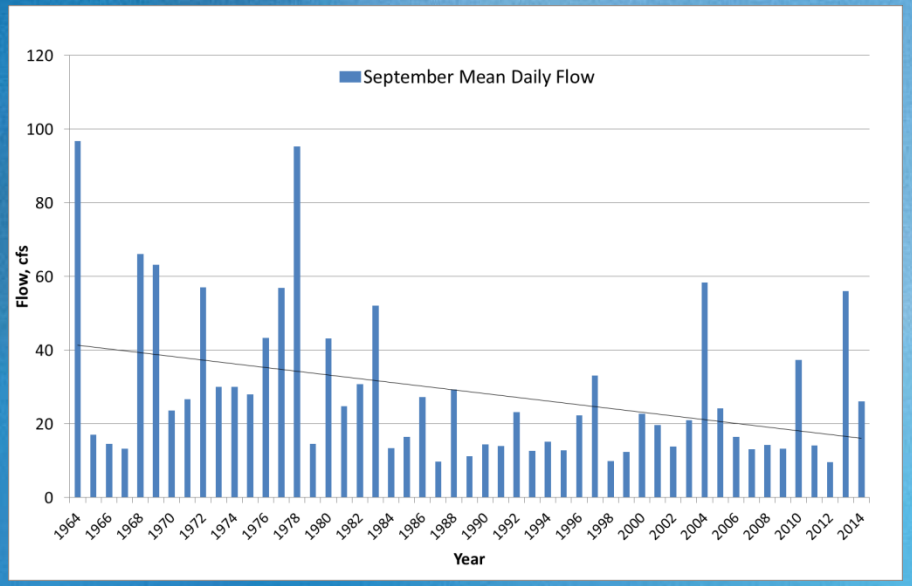


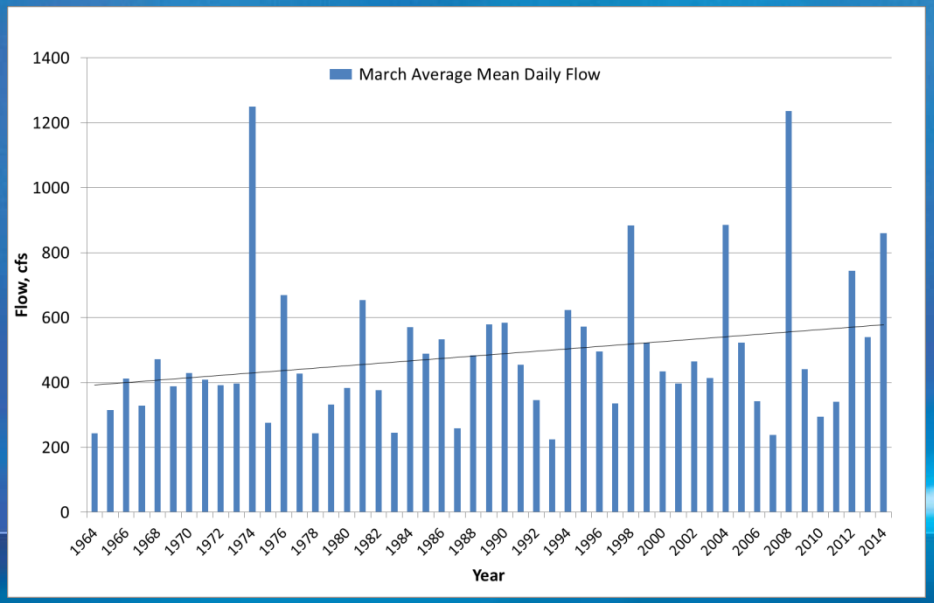
Peak Travel Time Snoqualmie to Carnation



Examples of Trends in Data







Potential Factors Impacting Hydrologic Changes

- Precipitation/Climate Change
- Timber Harvest
- Development
- Large Capital Projects
- Sediment

Precipitation

- Changes in precipitation impact flooding
- WSE compared precipitation trends at 8 gages throughout King County

What Precipitation Trends Show

- Precipitation in summer
- Precipitation in spring and fall
- Magnitude of major precipitation events

Climate Change Science for the PNW

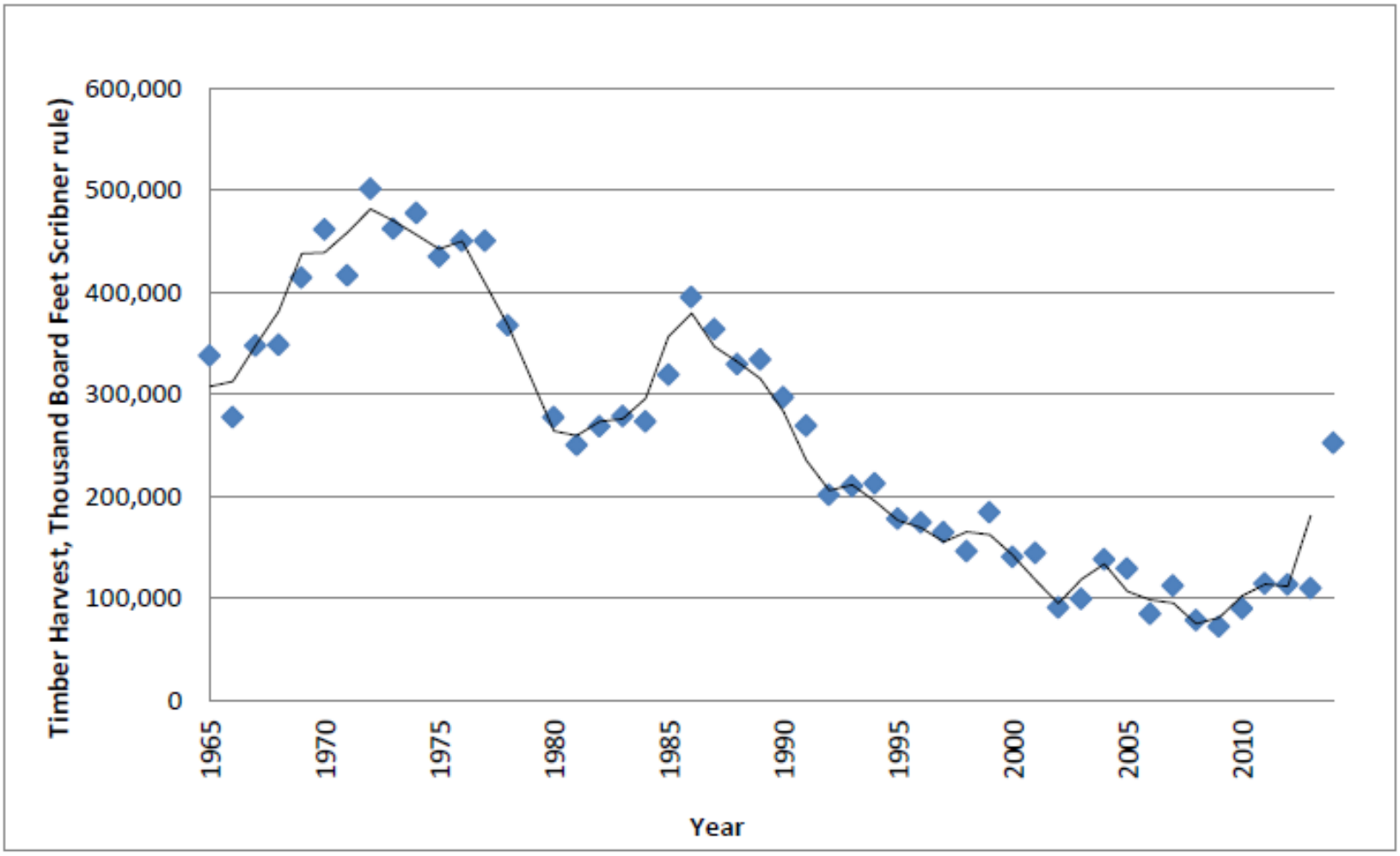
- ↑ Magnitude and Frequency of Atmospheric River Storm Events
- ↑ Temperatures
  - ↓ snow
  - ↑ rain
- = Yearly Precipitation Totals

Ongoing natural variation including El Niño / La Niña

Timber Harvest

- Reduced Forest Cover Results in:
  - Increased soil moisture
  - Increased snowmelt
  - Decreased runoff travel time

Logging is Down in King County



Source: WDNR (2015)

Figure 18. Reported Timber Harvest in King County 1965–2014.

Development

- Increased impervious area results in:
  - Decreased runoff travel time
  - Decreased evapotranspiration
  - Decreased infiltration and flood storage
- Increased runoff and flood peaks

Development

- Small portion of total basin area (4.3%)
  - 1.9 square miles of impervious area added from 1996 to 2010 (0.3% of basin)
- Stormwater regulations help to limit impact

Percentages based on NOAA C-CAP Land Cover Analysis

Large Capital Projects

- Changes the river and its floodplain
  - Chinook Bend, Farm Pad Program, Upper Carlson Levees…
- Subject to design review and flood impact evaluation

Large Capital Projects

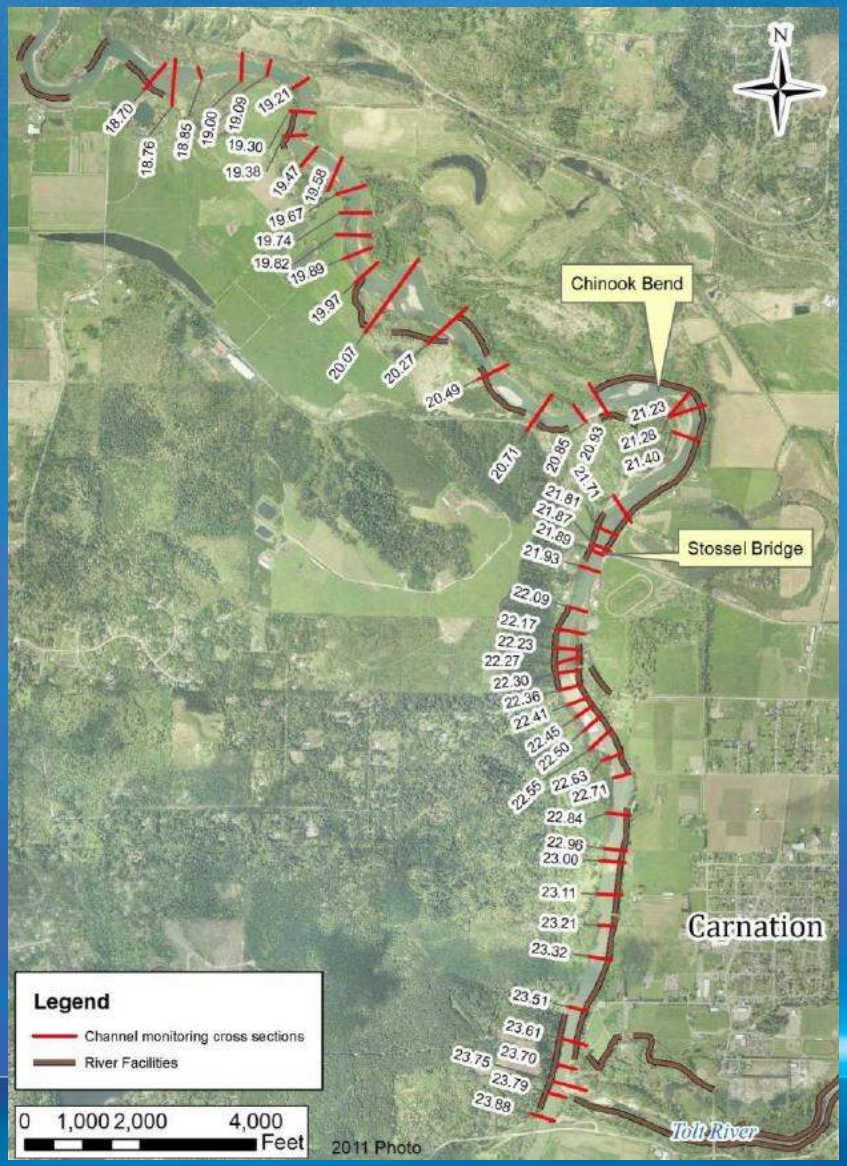
- Previous study evaluated the impacts of the PSE project and 205 projects
- Other projects have included hydraulic studies demonstrating no-impact

Sediment

- Increased channel bed levels result in:
  - Decreased channel capacity
  - Increased water surface elevation and flow in floodplain
- King County compared sediment data from 1965, 1997, 2004 and 2011

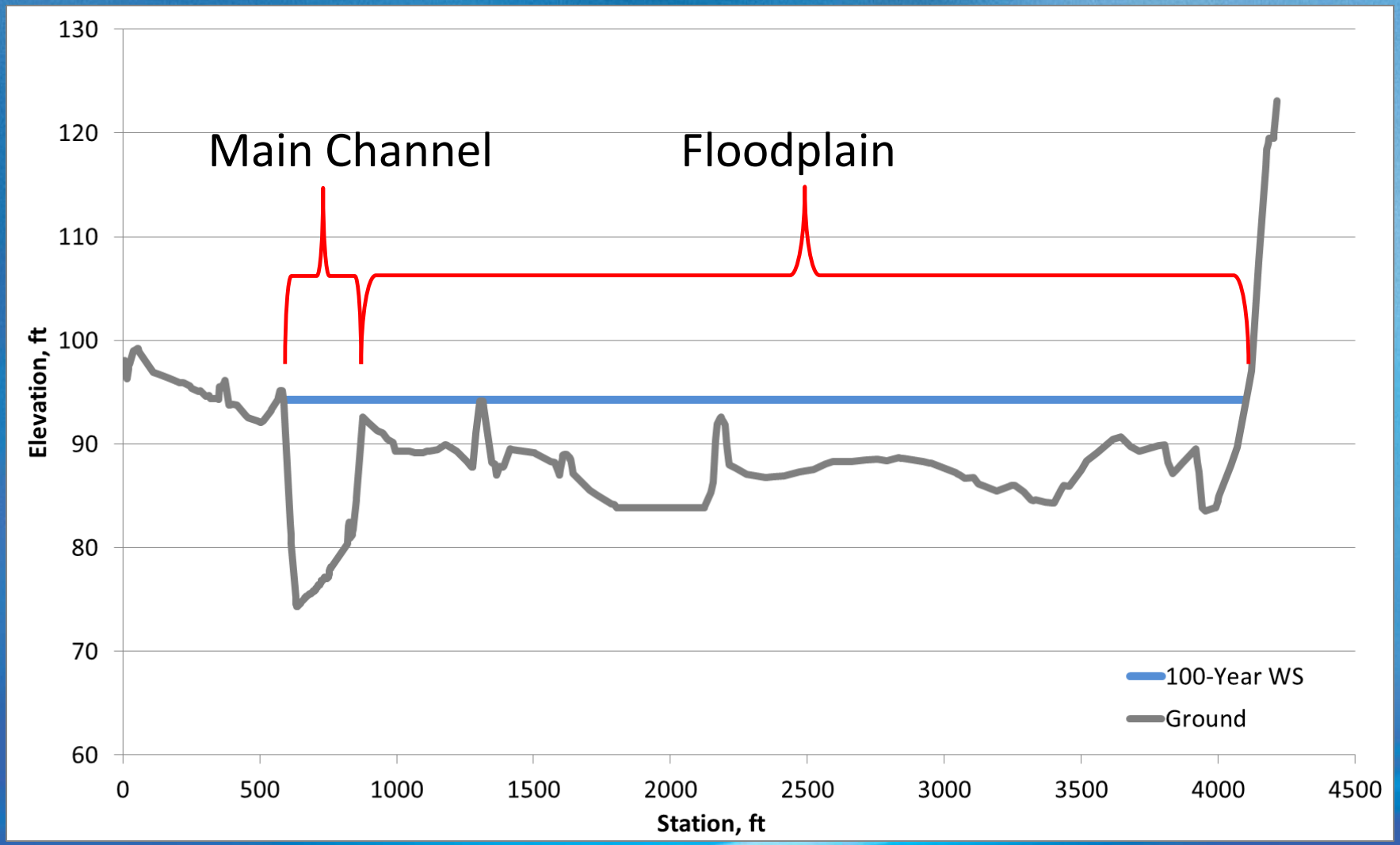
Sediment

Carnation Reach



Fall City Reach

Sediment


Main Channel
Floodplain
130
120
110
100
90
80
70
60
Elevation, ft
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Station, ft
100-Year WS
Ground

Summary

- Evidence of increasing flows in the fall and spring, and decreasing flows in the summer.
- Annual peak flows are trending upward but not statistically significant
- Individual floods vary due to a number of factors
- Flow and precipitation changes are consistent with changes expected due to climate change
- No finding that logging, development, sediment, or large capital projects have significantly impacted flows

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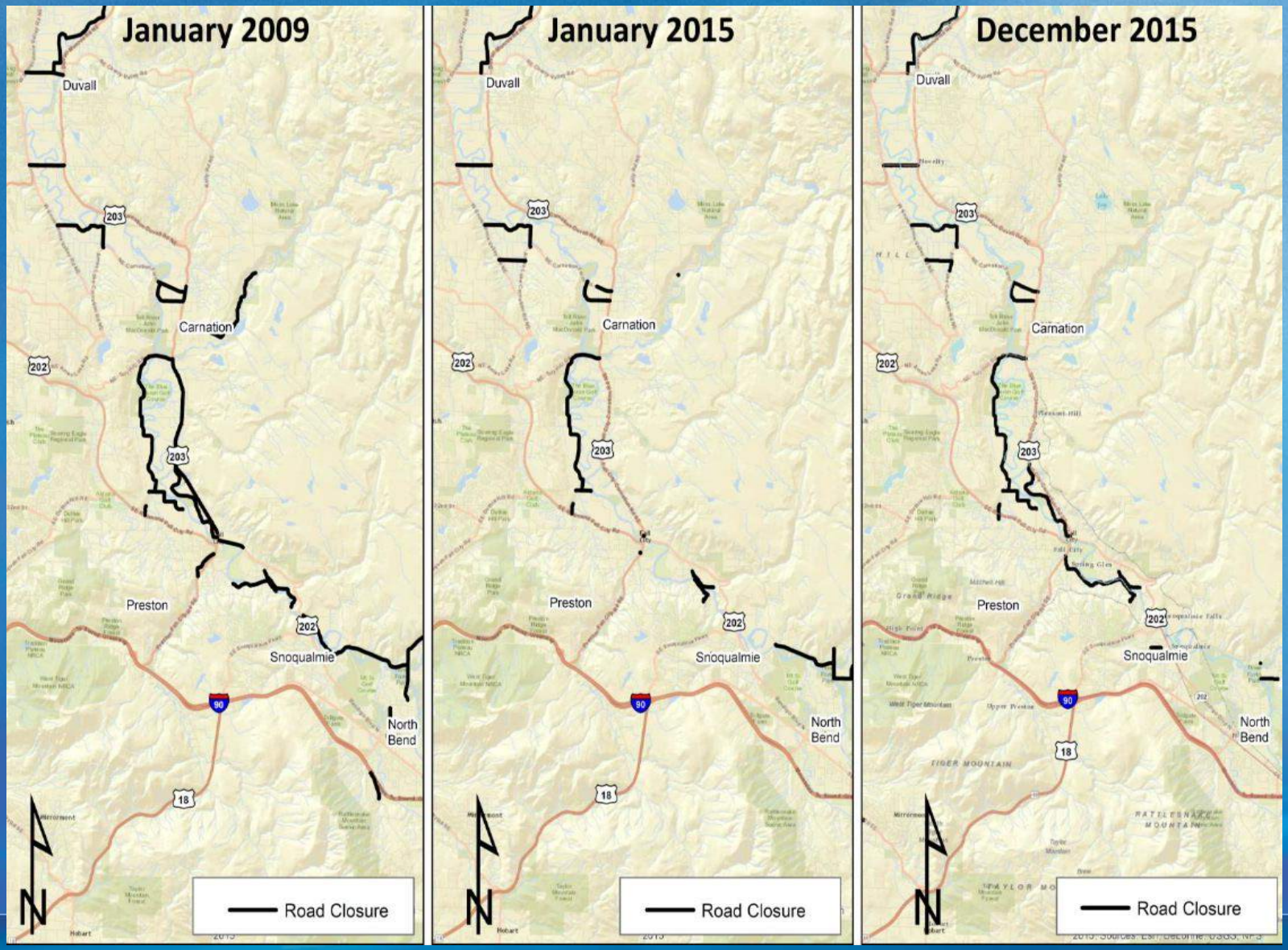
Event Comparison - Road Closures



Flow Trend Test Results

Station	Annual Average Daily Flow	Annual Maximum Daily Flow	Annual Peak Discharge	Count, 80% 2-Year Flow
NF Snoq nr Snoq Falls	↑	↑	↑	↑
MF Snoq nr Tanner	↑	↑	↑	↑
SF Snoq ab Alice Ck	↓	↑	↑	↑
Raging nr Fall City	↑	↑	↑	↑
Snoq nr Snoq	↑	↑	↑	↑
Snoq at Carnation	↓	↑	↑	↑

Legend		
<0.01	Very Strong Trend	↑
0.01-0.05	Strong Trend	↑
0.05-0.10	Weak Trend	↑
>0.10	No Significant Trend	↑ ↓
0.05-0.10	Weak Trend	↓
0.01-0.05	Strong Trend	↓
<0.01	Very Strong Trend	↓

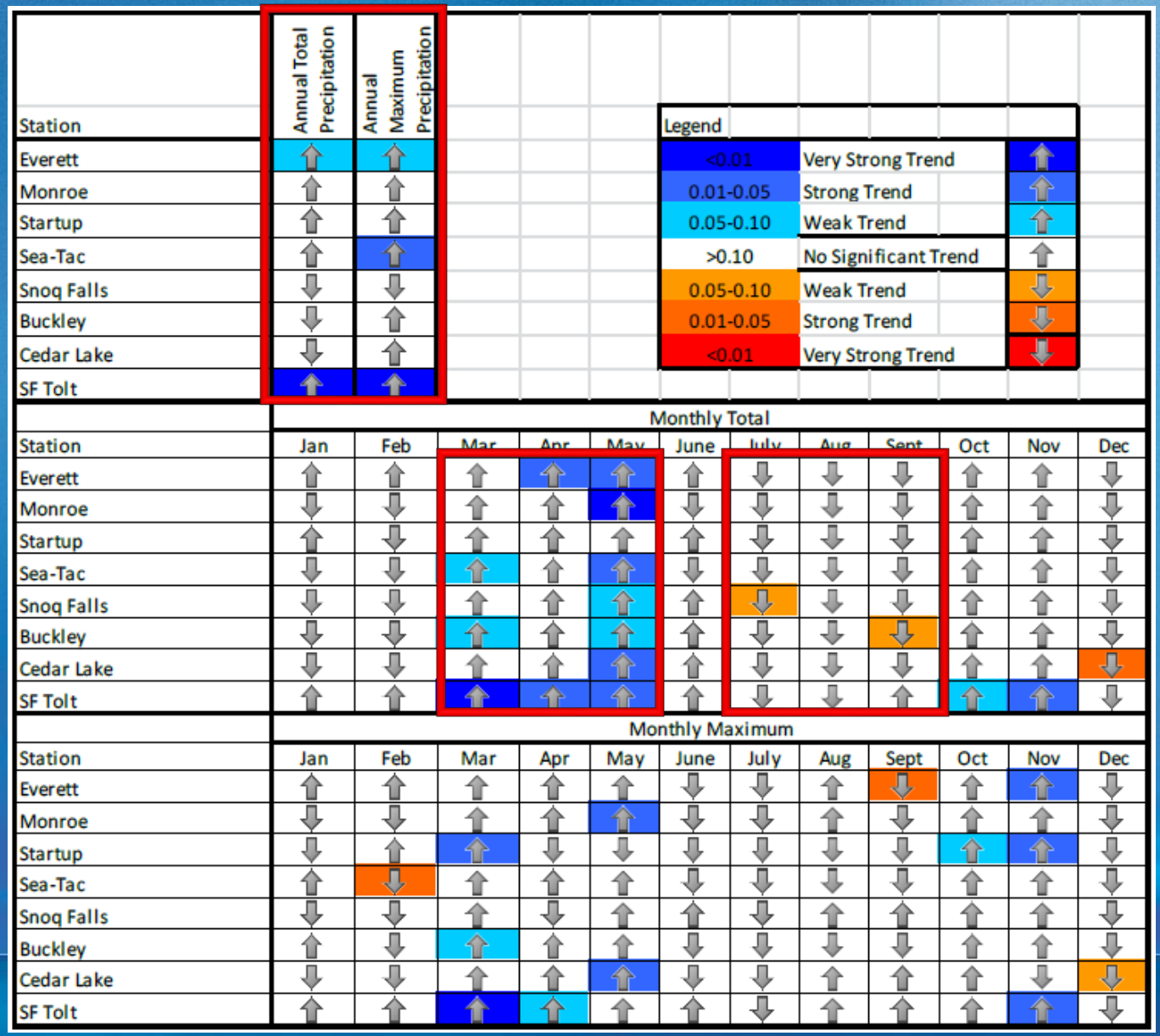
Monthly Average

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
NF Snoq nr Snoq Falls	↑	↓	↑	↑	↑	↑	↓	↓	↓	↑	↑	↓
MF Snoq nr Tanner	↓	↓	↑	↑	↑	↓	↓	↓	↓	↑	↑	↓
SF Snoq ab Alice Ck	↓	↓	↑	↑	↑	↓	↓	↓	↓	↑	↑	↓
Raging nr Fall City	↓	↓	↑	↑	↑	↑	↓	↓	↓	↑	↑	↓
Snoq nr Snoq	↓	↓	↑	↑	↑	↑	↓	↓	↓	↑	↑	↓
Snoq at Carnation	↓	↓	↑	↑	↑	↓	↓	↓	↓	↑	↑	↓

Monthly Maximum

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
NF Snoq nr Snoq Falls	↓	↓	↑	↑	↑	↑	↓	↓	↓	↑	↑	↓
MF Snoq nr Tanner	↓	↓	↑	↑	↑	↓	↓	↓	↓	↑	↑	↓
SF Snoq ab Alice Ck	↓	↓	↑	↑	↑	↓	↓	↓	↓	↑	↑	↓
Raging nr Fall City	↓	↓	↑	↑	↑	↑	↓	↓	↓	↑	↑	↓
Snoq nr Snoq	↓	↓	↑	↑	↑	↓	↓	↓	↓	↑	↑	↓
Snoq at Carnation	↓	↓	↑	↑	↑	↓	↓	↓	↓	↑	↑	↓

Precipitation



Station	Annual Total Precipitation	Annual Maximum Precipitation
Everett	↑	↑
Monroe	↑	↑
Startup	↑	↑
Sea-Tac	↑	↑
Snoq Falls	↓	↓
Buckley	↓	↑
Cedar Lake	↓	↑
SF Tolt	↑	↑

Legend		
<0.01	Very Strong Trend	↑
0.01-0.05	Strong Trend	↑
0.05-0.10	Weak Trend	↑
>0.10	No Significant Trend	↑
0.05-0.10	Weak Trend	↓
0.01-0.05	Strong Trend	↓
<0.01	Very Strong Trend	↓

Monthly Total

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Everett	↑	↑	↑	↑	↑	↑	↓	↓	↓	↑	↑	↓
Monroe	↓	↓	↑	↑	↑	↓	↓	↓	↓	↑	↑	↓
Startup	↑	↓	↑	↑	↑	↑	↓	↓	↓	↑	↑	↓
Sea-Tac	↓	↓	↑	↑	↑	↓	↓	↓	↓	↑	↑	↓
Snoq Falls	↓	↓	↑	↑	↑	↑	↓	↓	↓	↑	↑	↓
Buckley	↓	↓	↑	↑	↑	↑	↓	↓	↓	↑	↑	↓
Cedar Lake	↓	↓	↑	↑	↑	↑	↓	↓	↓	↑	↑	↓
SF Tolt	↑	↑	↑	↑	↑	↑	↓	↓	↑	↑	↑	↓

Monthly Maximum

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Everett	↑	↑	↑	↑	↑	↓	↓	↑	↓	↑	↑	↓
Monroe	↓	↓	↑	↑	↑	↓	↓	↑	↓	↑	↑	↓
Startup	↓	↑	↑	↓	↓	↓	↓	↓	↓	↑	↑	↓
Sea-Tac	↑	↓	↑	↑	↑	↓	↓	↓	↓	↑	↑	↓
Snoq Falls	↓	↓	↑	↓	↑	↑	↓	↑	↑	↑	↑	↓
Buckley	↑	↓	↑	↑	↑	↓	↓	↓	↓	↑	↑	↓
Cedar Lake	↓	↓	↑	↑	↑	↓	↓	↑	↑	↑	↓	↓
SF Tolt	↑	↑	↑	↑	↑	↑	↓	↑	↑	↑	↑	↓